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FRANK J. SEILER RESEARCH LABORATORY

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# EFFECTS OF CRITERIA ON FLIGHT SIMULATION: STUDY I - HEADING DEVIATION TOLERANCE



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PROJECT 2303

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE



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Twenty-eight United States Air Force Academy cadets were trained in a GAT-1 flight simulator under one of four experimental groups. The groups were defined first by having heading information either provided by the normal heading indicator or by peripheral lights and second by their being trained on either a 5° or a 10° heading deviation criterion. All cadets were subjected to four levels of a secondary cognitive task plus a control condition. There were no significant differences for either the main effect of heading indicator type or criterion

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level of training. The main effect of cognitive task difficulty level was significant for most measures. In addition, the heading indicator type by training criterion level interaction produced significant differences. Each significant interaction accounted for an average of 21% of the total variance. The study seems to indicate that training criteria are important independent variables in complex psychomotor/cognitive flight simulator tasks.

# PREFACE

This study was jointly sponsored by the Frank J. Seiler Research Laboratory work unit 2303-F1-54 and Aerospace Medical Research Laboratory, Aerospace Medical Division Contract AMD/RDO 78-1, Amendment 1.

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June 1980

## TABLE OF CONTENTS



## LIST OF ILLUSTRATIONS



## LIST OF TABLES

## INTRODUCTION

A series of experiments at the Air Force Academy was designed to study characteristics of human information processing in vision and attention during simulated flight. Some of these studies were aimed at improving pilot performance by means of alternate flight control monitoring devices such as displays placed in the peripheral fields of ambient vision. Other studies were aimed at investigating the training applications of these alternate forms of displays (e.g., Bermudez, Schwank, Longridge, Smith, and McCloy, 1979; Schwank, Bermudez, Smith, and Harris, 1979).

The present study is related to both of these research aims. In both lines of research, both system and operator performance data was obtained under conditions that approximate relevant information processing demands and realistic motor task demands. For example, the previous studies have required subjects to perform mental activity during either the difficult vertical S-"A" aerial maneuver, or during an instrument landing approach. The studies employed probed memory techniques, modified after the Sternberg technique (1969), to impose stress while the pilot flew the simulator. Although these earlier studies have shown memory probes are very demanding, the type of probe used seemed much less difficult than the types of processing demands and probes that typically confront the pilot. Previous memory probes have required little more than recognition memory for locations or for identity of a stimulus or for both (e.g., the location of dials and the identities of readings). In the present experiment, the secondary task included additional processing demands for the pilot to mentally manipulate and to transform data in addition to storing the result for later retrieval. It was assumed that the increased memory loads would interfere with the primary task in a linear fashion.

There is some evidence for the importance of the training criterion level for the purely cognitive task of verbal learning. Cofer (1969) presented some

of Weitz's arguments on the importance of the learning criteria. In that report, Weitz (1961) re-analyzed the data from a paired-associate study which was conducted by Cramer and Cofer (1960). When Weitz re-analyzed that data, he used several different criteria of second list learning. He found that the conclusions which could be reached varied greatly as a function of the particular learning criterion.

It seems reasonable to expect that various training criteria might also impact on learning to fly a simulator: a task which involves both psychomotor and cognitive components. That would be particularly true when an additional cognitive task was demanded of the subject. Curiously, we could not locate any studies which used training criteria as an independent variable to assess the strength of such effects. Therefore, the purpose of this study was to compare the effects of two levels of training criterion against two types of heading indicator visual displays in a flight simulator.

## Method

### Design

The design was a 2 x 2 x (5) mixed factorial with repeated measures on the last factor. There were two levels of compass heading error tolerance (5 versus 10 degrees) and there were two types of compass heading error indicators (typical dial compass versus light display). There were five levels of memory load (a no-load control, and four loads involving increasing amounts of information to process).

### Subjects

The subjects were male, novice Air Force Academy cadet pilots who had completed at least nine hours in a T-41 aircraft. The median was 21 hours. The cadets were randomly assigned, seven to each of the four experimental cells, in order of their appearance for the experiment.

## Apparatus

Flight Simulator. The flight simulator was the Link Group - General Precisions Systems, Incorporated, General Aviation Trainer-1 (GAT-1), Model Number N1926P. The GAT-1 was modified with black curtains to preclude any visual scene from outside the cockpit. The GAT-1 approximates the flight characteristics of the T-41C. The yoke was modified to include a button on its top left side which was used to signal responses to cognitive task questions.

Peripheral equipment included a console with cockpit repeater instruments; an intercom system to provide instructions; and, a Brush six-channel pressure ink recorder to record heading, airspeed, vertical velocity and responses to the secondary cognitive task.

Heading Indicators. Two groups of subjects used the typical T-41 dial compass which was mounted on the instrument panel. The remaining two groups used only a head-mounted system of peripheral vision signals with the dial compass masked from view. The LED signals consisted of five light-emitting diodes (LEDs), green in color, wired in series. Each LED was 2.4 mm in diameter with the LEDs placed six mm apart. The displays provided retinal projections at 55 degrees of arc subtended from the front, center of the person's head. Onset of the light occurred only when the pilot exceeded the desired heading by ± one degree. In order to correct an out-of-tolerance condition, the pilot's correct response was to turn towards the light and null the error.

Closed-Circuit Television. The visual secondary task was presented via a closed-circuit television monitor positioned in the GAT-1 windscreen.

Each visual presentation was a series of four slides and a no-slide control condition (see Figure 1). The minimal memory load target slide consisted of only a series of six "underlining" dashes. Low memory load had the six dashes, a letter above one dash and a single digit number above a different dash. Moderate memory load had the six dashes, one letter, and different single digit

numbers above three of the dashes. High memory load was comparable except that there were five different numbers plus the letter.

| | | | | | | |
|---|---|---|---|---|---|---|
| (Control) | (blank video) | | | | | |
| (Minimal) | ___ | ___ | ___ | ___ | ___ | ___ |
| (Low) | ___ | B | ___ | ___ | 8 | ___ |
| (Moderate) | 8 | ___ | 4 | ___ | A | 3 |
| (High) | 2 | 1 | 5 | F | 9 | 4 |

Figure 1. Target Slides

Three probe slides (see Figure 2) followed each target slide. The first probe contained the six dashes and an arrow pointing down towards one of them. The subject had to respond "yes" or "no" by pressing the button on the yoke to indicate whether or not the arrow pointed to the location of the letter on the target slide. The second probe slide contained only a letter. This probe asked whether or not this was the letter on the target slide, regardless of its location. The third probe slide asked whether or not the numerical value shown was equal to the transformation, i.e., the sum of the digits on the target slide. Sixty target slides were presented, 15 at each level. Each slide was shown for three seconds with a three second delay between slides.

(1) ___ ↓ ___ ___ ___ ___

(2) E

(3) 24

Figure 2. Probe slides.

## Procedure

Training. Subjects were told that the purpose of the study was to investigate their ability to respond to an additional task while flying the simulator. They were instructed that their first priority was to fly the simulator and that the extra task was secondary.

All pilots were trained to criterion on a vertical S-"A" aerial maneuver for one hour. This maneuver consists of ascending to an altitude of 2000 ft (656.17 m), then alternately, ascending and descending 250 ft (82.02 m) above and below the baseline. This maneuver had to be performed while holding to a heading of 270 degrees, airspeed of 80 mph (35.76 m/sec), and vertical climb and descent at 500 ft per minute (2.54 m/sec). This maneuver is very demanding and requires frequent motor activity and instrument scanning and cross-checking.

For two of the experimental groups, the criterion consisted of performing the vertical S-"A" without deviating more than 10 degrees from the desired heading. For the remaining two groups, the error tolerance was five degrees. Thus, there were four experimental groups: 5-DIAL, 10-DIAL, 5-LED, and 10-LED. An instructor pilot monitored performance during training and supplied prompts whenever heading deviations exceeded either the five or 10 degree training criterion.

Experiment. Experimental sessions occurred on the second day following training. Each subject was allowed five minutes of practice (two trials) after which four trials of the vertical S were performed. The subjects all performed a secondary task involving responding to 60 sets of visual stimuli and memory probes. The duration of each stimulus display was three seconds with a three second inter-stimulus delay.

Each visual presentation consisted of one of five types of video displays (see Figure 1), providing five levels of memory load: (1) zero or no load control, (2) memorizing that a display had blanks, (3) memorizing one letter, its location, and the sum of one number, (4) memorizing one letter, its location, and the sum of 3 numbers, and (5) memorizing one letter, its location, and the sum of 5 numbers. At each level of memory load, the cadets engaged in three cognitive activities: 1) localization, 2) identity, and 3) transformation (see Figure 2). The purpose of imposing the memory loads was to approximate levels

of cognitive demands analogous to the information processing demands of scanning and cross-checking instrument displays. All conditions were counterbalanced.

Dependent Measures. The following dependent measures were scored:

(1) Compass Heading errors. These errors were scored as absolute deviations from 270 degrees, sampled every five seconds during each two minute trial.

(2) Compass Heading overcorrections. These errors were scored as ratios of the number of times the pilot crossed from one side of the desired heading (270°) to the other side (e.g., 268° to 273°) per trial.

(3) Airspeed errors. These errors were scored as absolute deviations from 80 mph (35.76 m/sec) sampled every five seconds.

(4) Rate of Ascent/descent errors. These errors were scored as absolute deviations from the required 500 ft/min (2.54 m/sec) sampled every five seconds after the attitude was established.

(5) Error Time. This score consisted of the proportion of time the pilot erred by exceeding the five or 10 degree criterion during the experiment.

(6) Memory load scores. These scores consisted of the percent of correct responses to the 60 memory probes in the secondary task.

## Results

Table 1 presents the means and standard deviations for all measures of performance, at each level of memory load. A 2 (heading error tolerance) x 2 (compass type) x (5) (memory load) mixed analysis of variance on these data yielded significance for the memory load main effect, as follows: (a) compass heading errors, $F=8.25$, $p<.01$; (b) heading overcorrections, $F=15.30$, $p<.01$; (c) airspeed errors, $F=4.92$, $p<.01$ (all df = 4,96); (d) Error Time, $F(1, 15) = 8.26$, $p<.05$; and memory load scores, $F(3,66) = 14.19$, $p<.01$. The ascent/descent rate was not significant. Separate 2-tailed $t$-tests were calculated between the

control condition and each of the four memory load levels, and between the load levels only. These results are also outlined in table 1.

The ANOVA also yielded significance for several important interactions between the type of compass heading indicator and the error tolerance training criterion used in training. These results are presented in table 2.

The heading type by criterion level interaction was significant for heading errors, $\underline{F}$ $(1,24) = 7.056$, $\underline{p} < .05$ and accounts for 19% of the total variance. Figure 3 presents a graph of the means. Subjects in the 5° criterion groups performed better only if they were in the normal heading indicator group. However, if the training session allowed them 10° heading deviation, they subsequently performed better only if they received heading information from the peripheral lights.

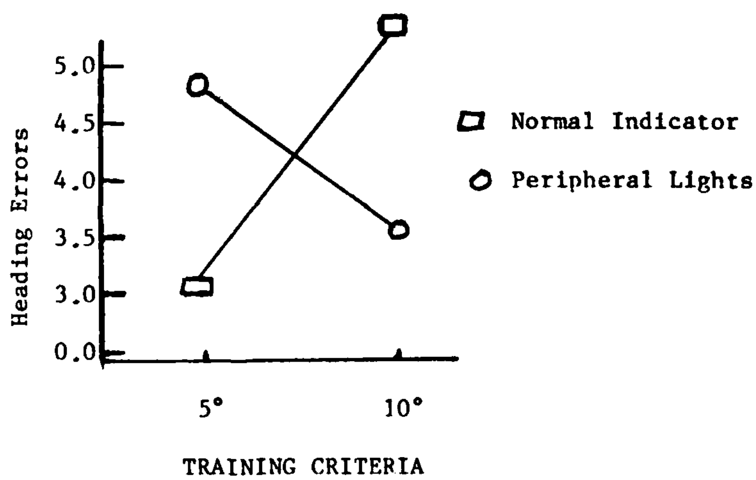


Figure 3. Mean absolute heading deviations as a function of heading indicator type and difficulty of training criteria.

Figure 4 illustrates the significant interaction of training criterion with heading type for overcorrections, $\underline{F}$ $(1, 24) = 11.649$, $\underline{p} < .01$ and accounts for 21% of the variance. In this case, those trained to the 5° heading deviations criterion had a smaller ratio of cross-overs if they used peripheral lights

TABLE 1

Means and Standard Deviations as a Function of Memory Load Level[a]

| Measures | SD | Control | Minimal | Low | Moderate | High |
|---|---|---|---|---|---|---|
| | | | | Memory Load Levels | | |
| Heading Errors | .11 | 3.63[d] | 4.05 | 4.17 | 4.44 | 4.38 |
| Overcorrections | 1.60 | 45.72 | 41.41[e] | 34.01 | 36.01 | 29.84 |
| Airspeed Errors | .17 | 4.10 | 4.36 | 4.73 | 4.70 | 5.07 |
| Rate Errors[b] | 3.74 | 105.23 | 107.12 | 105.42 | 110.35 | 100.89 |
| Error Time | 1.55 | 6.61 | 9.41 | 10.32 | 14.04 | 11.83 |
| Memory Scores | 1.33 | -[c] | 95.58 | 91.14 | 89.23 | 83.48 |

a. All tests were at the .01 level except Error Time (.05 level)
b. This was the only non-significant main effect.
c. There was no score in the control condition.
d. Single underline indicates significance between a control and other levels.
e. Double underline indicates significant differences between memory levels.

TABLE 2

Summary Results on Three Dependent Measures for the Interaction Between Type of Indicator and Level of Training Criterion

| | $F$ | $p$ | Omega$^2$ |
|---|---|---|---|
| Heading Errors | 7.06 (1,24) | .05 | 19% |
| Overcorrections | 11.65 (1,24) | .01 | 21% |
| Rate Error | 7.08 (1,24) | .05 | 17% |
| Error Time | 8.26 (1,15) | .05 | 27% |

Average Omega$^2$ (Variance Accounted for) = 21%

while those cadets using the normal heading indicator had a smaller ratio of cross-overs at the 10° criterion.

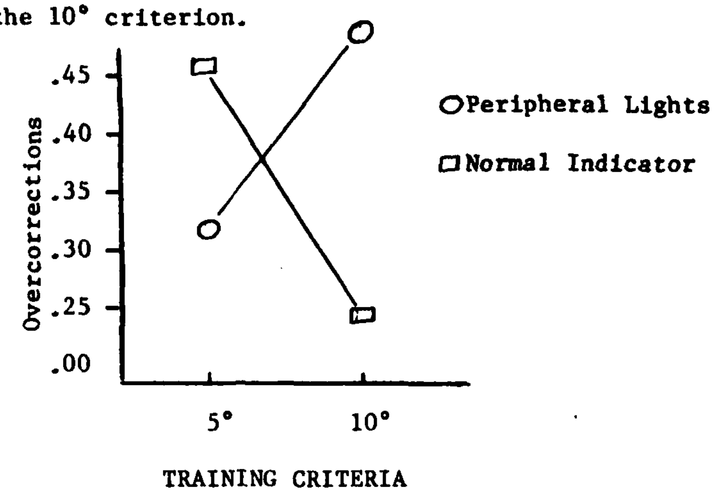


Figure 4. Ratio of number of times per 5 second interval that heading crossed over the desired 270° as a function of heading indicator type and level of training criteria.

The significant interaction between rate errors and the training criteria, $F\ (1,15) = 8.26$, $p < .05$, accounts for 27% of the variance and is presented in Figure 5. At the 5° heading deviation criterion, there were smaller proportions of rate errors if the cadets used the normal heading indicator. The reverse was true at the 10° heading deviation criterion, i.e., the cadets then performed better if they used the peripheral lights for heading information.

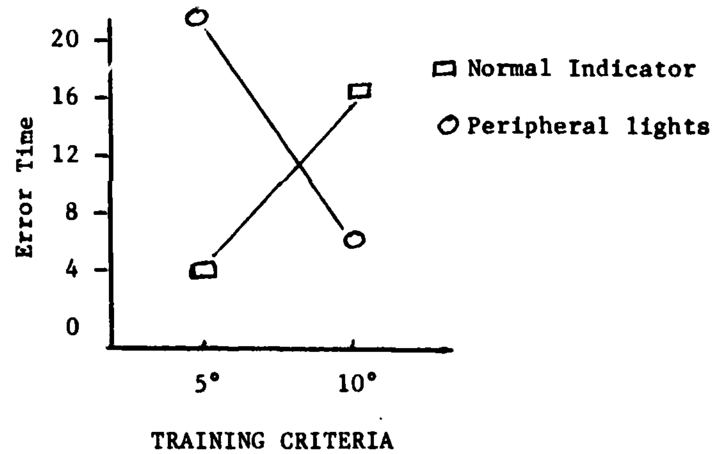


Figure 5. Proportion of time that heading equals or exceeded the maximum allowed deviation as a function of the training criteria.

There were two measures of flying proficiency that were not related to heading information. Airspeed deviations did not result in a significant statistic for the heading type by criterion level interaction. The heading type by criterion interaction was significant for vertical velocity deviations, $\underline{F}$ (1,24) = 7.080, $\underline{p} < .05$ and accounts for 17% of the variance (see Figure 6). Those trained at the 5° criterion performed better if they used the normal heading indicator: those trained at the 10° criterion performed better if they used the peripheral lights.

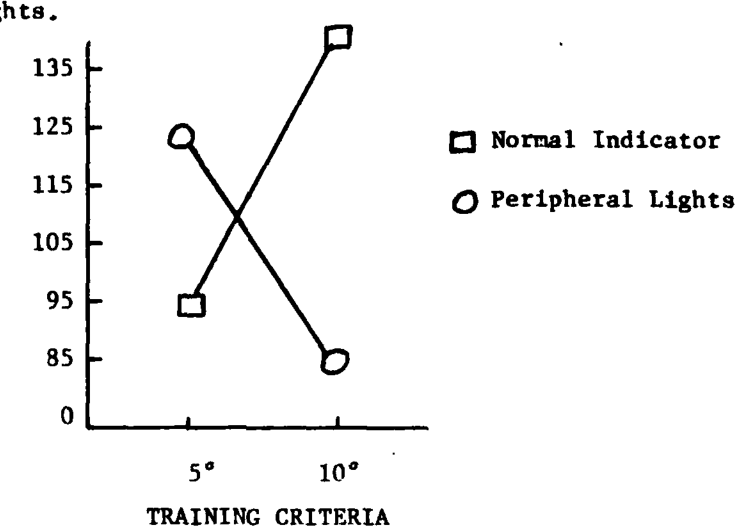


Figure 6. Mean vertical velocity deviations as a function of heading indicator type and difficulty of training criteria.

## DISCUSSION

In addition to flying the simulator, subjects were required to respond to a secondary, cognitive task. The ability to respond correctly to the secondary task decreased with increasing task level difficulty. With the exception of vertical velocity deviations, simulator performance also systematically declined as the secondary task level increased. Although pilots were told that their primary responsibility was to fly the simulator, it appears they were unable to isolate the secondary cognitive task from the primary task of flying the simulator.

Contrary to the original predictions, there were no statistically significant main effect differences for either the type of heading indicator or the training criteria levels for any of the measures. However, those two factors did have statistically significant interactions. Performance on the simulator was affected by the interaction between the type of heading indicator and the training criteria levels. Those interactions accounted for an average 21% of the variance and, therefore, the results seem to have practical as well as statistical significance.

These results clearly show that the superior simulator performance of the 5-DIAL and 10-LED groups cannot be attributed solely to the type of heading indicator used nor to the difficulty level of the training criterion alone. Instead, their performance was the result of the unique contribution of type of information display and the training criterion used with it. The concommitant failure to produce significant interactions as a result of the demands of the memory load tasks seems to once again point out the adaptability of the pilot to changing workloads. However, this adaptability did not generalize to the primary task as well for the two other experimental groups, indicating real differences in display type by criterion combinations. Also, contrary to our expectations and previous results, the greatest memory load proved not to be the most decremental on primary task performance. The expected linear function was not found. Presumably, once subjects have sufficient memory load they engage in some form of chunking strategies. The memory load thereby is reduced to fewer items, allowing more residual attention for the primary task.

These interpretations are strengthened by the fact that five of the six dependent measures are convergently consistent. For example, both the 5-DIAL and 10-LED groups produced the least number of heading errors, and, as would be expected, the <u>greatest</u> number of heading overcorrections. This indicates these two groups were not only the most accurate in maintaining heading but they were

also the most responsive in their attempts to be accurate. This view is further supported by the fact both groups also produced the lowest error time scores beyond the 5 and 10 degree training criterion thresholds. Furthermore, they also produced the most accurate performance in ascent/descent rate. That is, a performance measure which is strongly related to the heading correction task because, in attempting to maintain attention to heading, the pilot may sacrifice accuracy in his vertical climb or descent.

Perhaps some of the divergent results from earlier flight simulation studies were due to using various training criteria. For example, Puig et al (1978) reviewed the "motion issue" in flight simulation. They found little consistency relative to the effectiveness of platform motion in flight simulation research. The results of this research indicate that inclusion of the training criteria as an independent variable might aid in systematically demonstrating when platform motion is beneficial.

Previous literature suggests that the choice of criterion level can influence a purely cognitive task. This study indicates that the choice of criterion level also impacts research which also has psychomotor components.

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